Effect of Set-Up Heights on the Performance of Pot-In-Pot Cooling System for Storing Food and Drugs at Ambient Temperature

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Abstract— The research aimed at evaluating the effect of set-up height on the performance of earthenware pot-in-pot cooling system. The pots were set up at different heights; H1 (0 m), H2 (0.5 m) and H3 (1 m) and observed for 59 days from 8:00am to 6:00pm daily. The inner temperatures obtained from the three different arrangements were determined using standard methods. The result showed that increasing the height from ground level (0 m) to 1 m increases the mean cooling effect by 8 %. Generally, it was observed that only the set-up height at 1m proved to have maximum efficiency of the pot-in-pot system performance.

Keywords— Cooler, Efficiency, Evaporative cooling, Set-up height, Pot-in-pot, Preservation

1 INTRODUCTION

There is major environmental concern regarding convention nal refrigeration technologies including contribution to ozone layer depletion and global warming (Pedersen, 2006). In harsh dry climates in the northern part of Nigeria such as in Ilorin, food preservation plays a vital role in maximizing both economic and nutritional yield from the rare opportunity of a good harvest. The life of produce is significantly reduced by the dry heat and as a result there is a high level of wasted crop and reduces economic returns for rural farmers because of lack of or unreliable power in substantial number of communities in sub-Sahara Africa. This makes it difficult for food variety to be available long into the years and makes some drug storage a challenge, since some drugs are required to be stored at ‘room temperature’ 15°-25°C (59°-77°F) not at ambient temperature, which could be up to 30°C (Quick et al., 1997). Thus, alternative refrigeration technologies are required (Burton, 2007).

The viability of using evaporative cooling, namely; the pot-in-pot cooler was examined in Ilorin to provide clean energy and savings on the cost of food and drug preservation in the rural areas (Yahaya & Akande, 2018). The pot-in-pot cooling system, also known as adiabatic humidification and air-cooling device with simple heat exchange medium to lower final air temperature and reduce relative humidity, is interesting to most engineering field due to its simplicity, energy efficiency and zero pollution (Mehere, Mudafale, & Prayagi, 2014). Though by merely wetting a surface and allowing the water to evaporate effective cooling can be achieved but it is believed that the faster the rate of evaporation, the faster the rate of cooling (Libertya, Ugwuishiwu, Pukuma, & Odo, 2013). Also insight has been given to improving the performance of the pot-in-pot device by simple alteration of some components of the device such as its cover (Umesh, Majumdar, & Balakrishnan, 2016). Generally, the surface of a liquid is where evaporation takes place, wherein molecules that have attained high kinetic energy escape causing the average kinetic energy of the liquid to become lowered during the process, thereby decreasing the temperature of the liquid.

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Though, the maximum cooling that can be achieved is the reduction of air dry bulb temperature to wet bulb temperature (LaRoche, 2012). The main parameter considered when evaluating the performance of direct evaporative coolers is the Saturation Effectiveness (ε), given by equation 1, which can be defined as the ratio of values of depression of the temperature within the inner pots (Tin) below the ambient temperature (T_{Amb}) and the ambient wet bulb depression represented by the difference between the ambient temperature (T_{Amb}) and wet bulb temperature (T_{wet}) (ASHRAE, 1992).

$$\varepsilon = (T_{Amb} - T_{in})/(T_{Amb} - T_{wet}) \qquad (1)$$

The success of the pot-in-pot cooler is heavily reliant on the proximate conditions. Due to the device's dependence on natural evaporative cooling, it can only be view as an appropriate technology for regions that demonstrate a suitably low relative humidity and enough level of air flow (Longmone, 2003).

For molecules of a liquid to evaporate, they are required to be located near the surface, move in proper direction, and have sufficient kinetic energy to overcome liquid-phase intermolecular forces (Silberberg, 2006). As the molecules overcome this phase and the faster-moving molecules escape, the average kinetic energy of the remaining molecules become lower, and the temperature of the liquid decreases. This phenomenon is called evaporative cooling. Evaporation also tends to proceed more quickly with higher flow rates between the gaseous and liquid phase and in liquids with higher vapour pressure (Olosunde, Igbeka, & Olurin, 2009). For example, on a windy day, laundry on a clothes line will dry (by evaporation) more rapidly than on a still day. Thus, the three key parts to evaporation are heat, atmospheric pressure (determines the percent humidity) and air movement (Basediya, Samuel, & Beera, 2013).

Apart from the general requirements for the efficient operation of an evaporative cooling system, the efficiency of an active evaporative cooler depends on the rate and amount of evaporation of water (Wiersma, 1983; Dzivama, 2000). It has been demonstrated that the performance of the pot-in-pot cooling device can be enhanced by increasing air circulation around cooler to convert sensible heat to latent heat for greater performance and by employing intricate designs in high humidity and low temperature region (Jain, 2007). The air circulation can therefore be achieved by increasing the height on which the device is set up instead of placing it on the floor. However, questions on how high and how effective are yet to be answered. It is therefore the purpose of this research to investigate the effect of set up heights on the performance of the pot-in-pot cooling device.

Fig. 1: Comparison of the cooling effect at different height

2 Material and Methods

The study was carried out in the month of January and February 2014 in the University of Ilorin, Ilorin, capital city of Kwara State Nigeria. Ilorin is located on latitude 80 10′N and longitude 40 35′E marking a divide between the southern forest Zone and the Northern grassland of Nigeria.

The experiment was set up in a dry, ventilated space for the water to evaporate effectively towards the outside. The experiment uses two clay pots, one larger than the other, made from mud. 3 pots of 0.22 m2 surface area as the outer pots and 3 inner pots of 0.25 m in diameter were used. Sand was placed in the bottom of the 3 large pots of the same geometry forming a layer of approximately 5 cm in depth. The smaller pots were placed on top of the sand and centered in the large pots (which were set on the same level). The remaining spaces between the pots were filled with sand. The small pots were covered with wet towel to prevent hot air from entering the /storage chamber. Water was then added to make the lining media moist.

Each of the pot was placed at different heights, H_1 (0 m), H_2 (0.5 m), and H_3 (1 m) as shown in Fig 1. Digital thermometers with reading accuracy of ±0.1 °C were used to obtain the temperatures of the inner pots and surrounding. Hourly relative humidity data of Ilorin were obtained from Nigeria Meteorological Agency (NIMET) Ilorin and a digital clock was used to record the time interval. Data were collected for fifty-nine days at exact time and the average temperature and relative humidity were reported.

Efficiency (ε) as an important criterion to judge the evaporative cooling system was calculated as a temperature difference ratio (ASHRAE, 1992). The efficiency was calculated using equation 1.

Analysis of Variance (ANOVA) (Yandell, 1997) was used to test the hypotheses stated for the experiment, which are as follows:

H_0:μ_i=μ, for all i,i =1,2,3

H_1:μ_i≠μ, for at least one i,i=1,2,3

Where μ_i represents the mean temperature inside pot i and i stands for each pot used in the various experiment. The decision rule is given as: Reject H_0 if p-value is less than 0.05.

The wet bulb temperature was calculated using the formula (Stull, 2011):

$$T_{wet} = T * \arctan\left(0.015977(RH + 8.313659)^{\frac{1}{2}}\right) + \arctan(T + RH) - \arctan(RH - 1.676331) + 0.00391838 * RH^{\frac{3}{2}} * \arctan(0.023101 * RH) - 4.686035. \quad (2)$$

Where Twet = Wet Bulb Temperature in ºC; T = Air Temperature in ºC and RH = Relative Humidity of surrounding air in %.

3 Results and Discussion

3.1 Variation of Temperature Drop inside the Evaporative Cooling Systems

The air condition inside the evaporative cooler was recorded simultaneously with that of the atmospheric temperature around the cooler. These temperature changes were recorded hourly. Fig 1 shows the different heights at which the pot-in-pot devices were placed during the experiment and Fig 2 shows the difference in the cooling ability of the pot-in-pot at different heights: H_1 = Ground level, H_2 = 0.5 m and H_3 = 1 m. This shows that the higher to the ground the cooling system is, the cooler the inner pot. This might be due to flow of air completely around the pot to enhance available area for convection since air circulates better at higher altitude (Prabodh & Thamme, 2015).

The variation of dry-bulb temperature inside and outside the coolers versus time is as shown in Fig 2. The daily temperature reading within each cooler depends on ambient conditions. There was significant difference ($p < 0.05$) in each case between the temperature observed inside the coolers and the ambient temperature. The lowering of the dry-bulb temperature, which was clearly observed in the curve, is a measure of the effectiveness of the experimental set-up, which depends largely on the height of the set-up under the same ambient condition. As seen from the graph, there is significant difference between the inner temperatures of the three pots when compared to the ambient temperature. However, there exists no significant difference between H_1 and H_2 as well as between H_2 and H_3 because their p values are above 0.05 but there exists significant difference between the mean inner temperature of H_1 and H_3 with a p value of 0.02 that is less than 0.05.

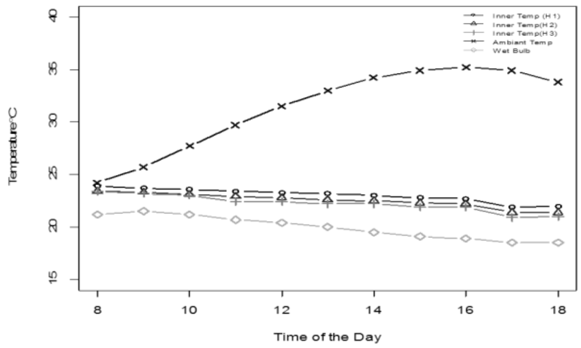

Fig. 2: Comparison of the dry bulb temperature of outside and inside the pots at various heights versus time of the day

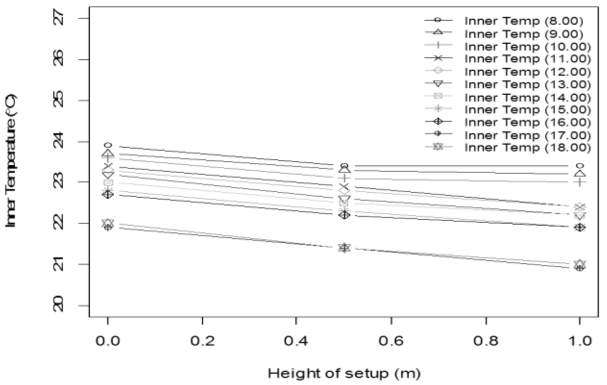

Fig. 3: Comparison of inner temperature for different heights at various hours

At 11.00 hour, when the pot-in-pot device seems to have transferred most heat from inside the pot to the sand, there seems to be a sharp drop in temperature inside the pot as shown in Fig 3. The system demonstrates the lowest temperature at 17.00 hour when the sun isn't as harsh and the cumulative effect of the functioning of the device since its operation could be felt.

3.2 Cooling Efficiency of the Evaporative Cooling System

Instead of using temperature difference (T_{Amb} - T_{in}) as the parameter to compare the cooling effect of an evaporative cooling system, the use of the ratio of values of depression of the temperature within the inner pots (Tin) below the ambient temperature (T_{Amb}) and the ambient wet bulb depression i.e. (T_{Amb} - T_{in})/ (T_{Amb} – T_{wet}) gives an accurate basis of comparison between locations

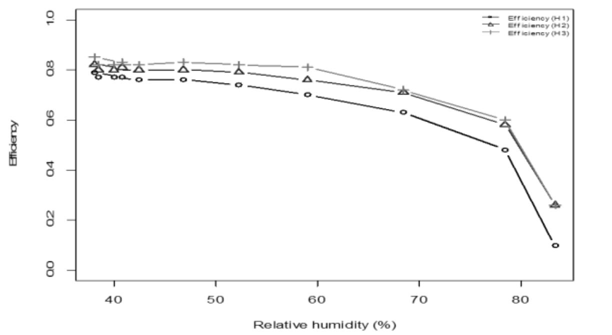

Fig. 4: Graph of Efficiency vs. Relative Humidity (%) for different set up height

of different humidity and ambient air distribution (Olorunmaiye, 1996). The efficiencies of the various set-ups are given as shown in Table 1. Even at same environmental condition (relative humidity), the efficiency of the pot-in-pot cooling devices varies between the various experimental set up height as shown in Fig 4.

The ANOVA tests done on the height of the setup produced p-values of 0.02893 since this p-value for the test is clearly less than 0.05, our hypothesis one (H_1) will be accepted. It is safe to say the mean temperature in the inner pot for the three set up heights (H_1, H_2 and H_3) are significantly different from one another. Sequel to this conclusion reached, a pair wise comparison is required to determine the difference comparing each pair to know if the mean efficiency comparatively differ from one set up height to the other e.g. H_1 and H_2, H_2 and H_3 as well as H_1 and H_3. Tukey HSD test (Yandell, 1997) was used for this purpose. A decision was also reached based on the p-values obtained from the test. The pair compared, and the corresponding p-values were; H_1 and H_2 is 0.2248094, H_1 and H_3 is 0.0229768 and H_2 and H_3 is 0.5037189. From the p-values above, it can be concluded that only the inner temperature at height H_1 and height H_3 are significantly different from each other. So, raising the device just 0.5 m above the ground is insufficient to contribute meaningfully to the performance of the device but raising the cooling system to at least 1m above the ground would be suitable to establish increase in the effective performance of the device.

Table 1. Comparison of the Efficiencies of different heights of pot-in-pot

Time of Day	Average of reading										
	Inner Temperature T_{in} (°C)			Ambient Temp.	Wet bulb Temp.	Relative Humidity	Wind Speed	T_{Amb} - T_{wet}	ε = (T_{Amb} - T_{in})/(T_{Amb} - T_{wet})		
	H1	H2	H3	(°C)	(°C)	(%)	(m/s)	(°C)	H1	H2	H3
8.00	23.9	23.4	23.4	24.2	21.2	83.3	2.4	3.0	0.10	0.26	0.26
9.00	23.7	23.3	23.2	25.7	21.5	78.4	3.1	4.1	0.48	0.58	0.60
10.00	23.6	23.1	23.0	27.7	21.2	68.4	4.2	6.5	0.63	0.71	0.72
11.00	23.4	22.9	22.4	29.7	20.7	59.0	3.9	9.0	0.70	0.76	0.81
12.00	23.3	22.8	22.4	31.5	20.4	52.3	3.6	11.1	0.74	0.79	0.82
13.00	23.2	22.6	22.2	33.0	20.0	46.8	3.8	13.0	0.76	0.80	0.83
14.00	23.0	22.5	22.2	34.2	19.5	42.5	2.9	14.6	0.76	0.80	0.82
15.00	22.8	22.3	21.9	34.9	19.1	40.0	3.4	15.8	0.77	0.80	0.82
16.00	22.7	22.2	21.9	35.2	18.9	38.5	3.1	16.3	0.77	0.80	0.82
17.00	21.9	21.4	20.9	34.9	18.5	38.1	3.2	16.4	0.79	0.82	0.85
18.00	22.0	21.4	21.0	33.8	18.5	40.8	3.2	15.3	0.77	0.81	0.84

4 Conclusion

The height at which the pot-in-pot device is set up is the primary parameter that was addressed in this analysis to evaluate the performance of the device. This research has experimentally shown that by increasing the height of set up from the ground level to 0.5 m high, the mean efficiency of the device increased by 6 % and an 8 % increase in mean efficiency was obtained when placed 1 m above the ground level. Though it is identified that only a meter increase in height of set up benefits the system because only the inner temperature at height H1 and height H3 are significantly different from each other since the p-value is less than 0.05. It is hope that this work will help inform communities willing to benefit from the use of the earthenware pot-in-pot cooling devices for farm produce preservation or drug storage in rural areas.

There is need to construct a standard pot holder in order to maximize the effect of air circulation but may contribute to the cost of the cooling device. The 9% increase in efficiency may be sacrificed for cost saving. It is also not worth investing on a pot support stand should it be less than one-meter high. A load test of the gadget at different heights could also prove this increase in efficiency worthy or otherwise.

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